

03R00206

SEMICONDUCTOR LIGHT EMITTING DEVICE AND
METHOD FOR PRODUCING THE SAME

BACKGROUND OF THE INVENTION

1. FIELD OF THE INVENTION:

The present invention relates to a semiconductor
5 light emitting device used for an optical recording
apparatus, an optical transmission apparatus or the like,
and a method for producing the same.

2. DESCRIPTION OF THE RELATED ART:

10 Recently, optical recording apparatuses and
optical transmission apparatuses have been used in various
apparatuses in information related fields.
Semiconductor laser devices used as semiconductor light
emitting devices in these optical recording apparatuses
15 and optical transmission apparatuses have been required
to have high performances in terms of speed, output and
the like.

As devices in information related fields are used
20 more and more in households, the semiconductor laser
devices used in these optical recording apparatuses and
optical transmission apparatuses are required to be
inexpensive. For example, semiconductor laser devices
used in optical recording apparatuses, for example, DVD

apparatuses are especially required to have high performance at low prices.

Figures 5A through 5D are cross-sectional views illustrating steps of a method for producing a semiconductor laser device 200 used in a DVD apparatus.

As shown in Figure 5A, an n-type GaInP buffer layer 102, an n-type first AlGaInP clad layer 103, an undoped GaInP/AlGaInP strained multiple quantum well active layer 104, a p-type second AlGaInP clad layer 105, a p-type GaInP etching stop layer 106, a p-type third AlGaInP clad layer 107', a p-type GaInP intermediate layer 108', and a p-type GaAs cap layer 109' are formed in a stacking manner in this order on an n-type GaAs substrate 101 by molecular beam epitaxy (MBE). Then, an Al₂O₃ layer 110' is formed on the p-type GaAs cap layer 109' by electron beam (EB) deposition.

Next, as shown in Figure 5B, the p-type third AlGaInP clad layer 107', the p-type GaInP intermediate layer 108', the p-type GaAs cap layer 109', and the Al₂O₃ layer 110' are processed with photolithography and etching, thereby forming a striped ridge structure including a

p-type third AlGaInP clad layer 107, a p-type GaInP intermediate layer 108, a p-type GaAs cap layer 109, and an Al₂O₃ layer 110. The striped ridge structure is formed in a central area of a top surface of the p-type GaInP etching stop layer 106.

As shown in Figure 5C, the structure on the n-type GaAs substrate 101 is entirely rinsed with a sulfuric acid-based rinsing solution, and then washed with pure water. An n-type AlInP current confinement layer 111 is formed on the p-type GaInP etching stop layer 106 so as to cover the striped ridge structure by MBE. This step forms an unnecessary layer 112 of n-type AlInP on the Al₂O₃ layer 110.

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As shown in Figure 5D, the Al₂O₃ layer 110 and the unnecessary layer 112 are removed. A p-type GaAs contact layer 113 is formed on the p-type GaAs cap layer 109 and the n-type AlInP current confinement layer 111. Then, a p-type electrode 114 is formed on the p-type GaAs contact layer 113, and an n-type electrode 115 is formed on a bottom surface of the n-type GaAs substrate 101.

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In this manner, the semiconductor laser device 200

having a waveguide with a buried ridge structure is produced.

5 The above-described method for producing the semiconductor laser device 200 has the following problems. Depending on the process conditions, the oscillation threshold current I_{th} , which is a starting point of laser oscillation, may be increased, which causes variability in the production yield of the semiconductor laser devices.

10 This is a cause of the increased cost of semiconductor laser devices. In addition, as the oscillation threshold current I_{th} is increased, the malfunction rate of the semiconductor laser device is increased when continuously used for a long period of time and thus the reliability

15 is lowered.

SUMMARY OF THE INVENTION

20 According to one aspect of the invention, a semiconductor light emitting device includes a semiconductor substrate; a stacked semiconductor structure formed on the semiconductor substrate; a striped ridge structure; and a semiconductor current confinement layer provided on a side surface of the striped ridge

structure. The stacked semiconductor structure includes a first semiconductor clad layer, a semiconductor active layer, a second semiconductor clad layer, and a semiconductor etching stop layer. The striped ridge structure includes a third semiconductor clad layer, a semiconductor intermediate layer, and a semiconductor cap layer. The striped ridge structure is provided on the semiconductor etching stop layer. An interface between the semiconductor current confinement layer and the semiconductor etching stop layer and an interface between the semiconductor current confinement layer and the striped ridge structure each have a content of impurities of less than $1 \times 10^{17}/\text{cm}^3$.

15 In one embodiment of the invention, the impurities are carbon-based impurities.

In one embodiment of the invention, the impurities are oxygen-based impurities.

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In one embodiment of the invention, the impurities are carbon-based impurities and oxygen-based impurities.

According to another aspect of the invention, a

method for producing a semiconductor light emitting device includes the steps of forming a first stacked semiconductor structure on a semiconductor substrate, the first stacked semiconductor structure including a first semiconductor clad layer, a semiconductor active layer, a second semiconductor clad layer and a semiconductor etching stop layer; forming a second stacked semiconductor structure on the semiconductor etching stop layer, the second stacked semiconductor structure including a third semiconductor clad layer, a semiconductor intermediate layer and a semiconductor cap layer; forming an oxide layer on the second stacked semiconductor structure; processing at least the second stacked semiconductor structure into a striped ridge structure; washing the first stacked semiconductor structure and the striped ridge structure with a washing liquid having a prescribed resistivity; and forming a semiconductor current confinement layer on a side surface of the striped ridge structure.

20 In one embodiment of the invention, the prescribed resistivity is higher than 1 MΩm.

 In one embodiment of the invention, the washing liquid is pure water.

In one embodiment of the invention, the prescribed resistivity is higher than 1 MΩm.

5 According to a semiconductor light emitting device of the present invention, the interface between the semiconductor current confinement layer and the semiconductor etching stop layer and the interface between the semiconductor current confinement layer and the ridge
10 structure each have an impurity content of less than $1 \times 10^{17}/\text{cm}^3$. Therefore, absorption of light by the impurities is suppressed, the oscillation threshold current I_{th} is stable without being abnormally increased, the malfunction rate when continuously used for a long
15 period of time is lowered, and the reliability is improved.

Thus, the invention described herein makes possible the advantages of providing a semiconductor light emitting device for suppressing the increase in the
20 oscillation threshold current I_{th} and improving the reliability, and a method for producing the same.

These and other advantages of the present invention will become apparent to those skilled in the

art upon reading and understanding the following detailed description with reference to the accompanying figures.

BRIEF DESCRIPTION OF THE DRAWINGS

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Figure 1 is a cross-sectional view of a semiconductor laser device according to an example of the present invention;

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Figures 2A through 2D are cross-sectional views illustrating a method for producing the semiconductor laser device shown in Figure 1;

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Figure 3A is a graph illustrating the correlation between the content of carbon-based impurities in a re-growth interface area of an n-type AlInP current confinement layer of a semiconductor laser device and the oscillation threshold current I_{th} of the semiconductor laser device;

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Figure 3B is a graph illustrating the correlation between the content of oxygen-based impurities in the re-growth interface area of the n-type AlInP current confinement layer of a semiconductor laser device and the

oscillation threshold current I_{th} of the semiconductor laser device;

Figure 4A is a graph illustrating the correlation
5 between the content of carbon-based impurities in the re-growth interface area of the n-type AlInP current confinement layer of a semiconductor laser device and the resistivity of pure water used for producing the semiconductor laser device;

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Figure 4B is a graph illustrating the correlation
between the content of oxygen-based impurities in the re-growth interface area of the n-type AlInP current confinement layer of a semiconductor laser device and the
15 resistivity of pure water used for producing the semiconductor laser device; and

Figures 5A through 5D are cross-sectional views
illustrating a method for producing a semiconductor laser
20 device.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Samples of each layer of the semiconductor laser

device 200 produced by the method shown in Figure 5A through 5D were analyzed in terms of crystalline state and the like using a SIMS (secondary ion mass spectrometer) and the like. The following was found.

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In a semiconductor laser device of a lot having an abnormally high oscillation threshold current I_{th} , the content of carbon-based impurities and oxygen-based impurities at the interface between the n-type AlInP current confinement layer 111 and the p-type GaInP etching stop layer 106 and the interface between the n-type AlInP current confinement layer 111 and the striped ridge structure 116 (more specifically, the re-growth interface area of the n-type AlInP current confinement layer 111) 10 was confirmed to be higher than that of a semiconductor laser device of a lot having a normal oscillation threshold current I_{th} . 15

It was also confirmed that the content of the carbon-based impurities and oxygen-based impurities in 20 the re-growth interface area of the n-type AlInP current confinement layer 111 was closely related to the resistivity of pure water used for washing. The resistivity of pure water represents the purity of the

pure water. As described above, washing with pure water is performed after rinsing with a sulfuric acid-based rinsing solution before the n-type AlInP current confinement layer 111 is formed (re-grown).

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Figure 3A is a graph illustrating the correlation between the oscillation threshold current I_{th} of the manufactured semiconductor laser device 200 and the content of carbon-based impurities in the re-growth interface area of the n-type AlInP current confinement layer 111. Figure 3B is a graph illustrating the correlation between the oscillation threshold current I_{th} of the manufactured semiconductor laser device 200 and the content of oxygen-based impurities in the re-growth interface area of the n-type AlInP current confinement layer 111.

As shown in Figure 3A, when the content of carbon-based impurities in the re-growth interface area of the n-type AlInP current confinement layer 111 is lower than $1 \times 10^{17}/\text{cm}^3$, the oscillation threshold current I_{th} is stable at around 25 mA.

As shown in Figure 3B, when the content of

oxygen-based impurities in the re-growth interface area of the n-type AlInP current confinement layer 111 is lower than $1 \times 10^{17}/\text{cm}^3$, the oscillation threshold current I_{th} is stable at around 25 mA.

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When the content of carbon-based impurities and the content of oxygen-based impurities in the re-growth interface area of the n-type AlInP current confinement layer 111 are each higher than or equal to $1 \times 10^{17}/\text{cm}^3$, the oscillation threshold current I_{th} significantly increases.

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Figure 4A is a graph illustrating the relationship between the content of carbon-based impurities in the re-growth interface area of the n-type AlInP current confinement layer 111 and the resistivity of pure water. Figure 4B is a graph illustrating the relationship between the content of oxygen-based impurities in the re-growth interface area of the n-type AlInP current confinement layer 111 and the resistivity of pure water.

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As shown in Figures 4A and 4B, when the resistivity of pure water is higher than 1 MΩm, the content of carbon-based impurities and the content of oxygen-based

impurities in the re-growth interface area of the n-type AlInP current confinement layer 111 are each less than $1 \times 10^{17}/\text{cm}^3$. When the resistivity of pure water is lower than or equal to 1 M Ωm , the content of carbon-based impurities and the content of oxygen-based impurities in the re-growth interface area of the n-type AlInP current confinement layer 111 are each higher than or equal to $1 \times 10^{17}/\text{cm}^3$.

Thus, it was confirmed that the increase in the oscillation threshold current I_{th} is suppressed by maintaining the resistivity of pure water at a value higher than 1 M Ωm .

One example of the carbon-based impurities is carbon dioxide, and one example of the oxygen-based impurities is phosphoric acid.

Hereinafter, the present invention will be described by way of illustrative examples with reference to the accompanying drawings.

Figure 1 is a cross-sectional view of a semiconductor laser device 100 as a semiconductor light

emitting device according to an example of the present invention.

The semiconductor laser device 100, as an exemplary
5 semiconductor light emitting device, includes an n-type
GaAs substrate 1, a stacked semiconductor structure 17
provided on the n-type GaAs substrate 1, a striped ridge
structure (waveguide) 16, an n-type AlInP current
confinement layer 11 provided on side surfaces of the
10 striped ridge structure 16, a p-type GaAs contact layer
13, a p-type electrode 14 and an n-type electrode 15.

The stacked semiconductor structure 17 includes
an n-type GaInP buffer layer 2, an n-type first AlGaInP
15 clad layer 3, an undoped GaInP/AlGaInP strained multiple
quantum well active layer 4, a p-type second AlGaInP clad
layer 5, and a p-type GaInP etching stop layer 6. These
layers are stacked sequentially in this order.

20 The striped ridge structure 16 includes a p-type
third AlGaInP clad layer 7, a p-type GaInP intermediate
layer 8, and a p-type GaAs cap layer 9. These layers are
stacked sequentially in this order. The striped ridge
structure 16 is formed on a central portion of the p-type

GaInP etching stop layer 6.

The n-type AlInP current confinement layer 11 is provided on the p-type GaInP etching stop layer 6 so as to cover the striped ridge structure (waveguide) 16 except for a top surface of the p-type GaAs cap layer 9. At least one of the content of carbon-based impurities and the content of oxygen-based impurities at the interface between the n-type AlInP current confinement layer 11 and the p-type GaInP etching stop layer 6 and the interface between the n-type AlInP current confinement layer 11 and the striped ridge structure 16 (more specifically, the re-growth interface area of the n-type AlInP current confinement layer 11) is less than $1 \times 10^{17}/\text{cm}^3$. Preferably, the total of the content of carbon-based impurities and the content of oxygen-based impurities is less than $1 \times 10^{17}/\text{cm}^3$.

The p-type GaAs contact layer 13 is provided on the p-type GaAs cap layer 9 and the n-type AlInP current confinement layer 11. The p-type electrode 14 is provided on the p-type GaAs contact layer 13, and the n-type electrode 15 is provided on a bottom surface of the n-type GaAs substrate 1.

In the semiconductor laser device 100 shown in Figure 1 according to a preferred embodiment of the present invention, the total content of carbon-based impurities and oxygen-based impurities at the re-growth interface area of the n-type AlInP current confinement layer 11 is less than $1 \times 10^{17}/\text{cm}^3$ (alternatively, at least one of the content of carbon-based impurities and the content of oxygen-based impurities at the re-growth interface area of the n-type AlInP current confinement layer 11 is less than $1 \times 10^{17}/\text{cm}^3$), as described above. Therefore, the oscillation threshold current I_{th} is at a stable level. Since the oscillation threshold current I_{th} is not abnormally increased, the malfunction rate of the semiconductor laser device when continuously used for a long period of time is reduced, and thus the reliability is improved.

The semiconductor laser device 100 having the above-described structure is produced as follows as shown in Figures 2A through 2D.

As shown in Figure 2A, the n-type GaInP buffer layer 2, the n-type first AlGaInP clad layer 3, the undoped

GaInP/AlGaInP strained multiple quantum well active layer 4, the p-type second AlGaInP clad layer 5, and the p-type GaInP etching stop layer 6 are formed in a stacking manner in this order on the n-type GaAs substrate 1 by MBE. Thus, the stacked semiconductor structure 17 is produced. Then, a p-type third AlGaInP clad layer 7', a p-type GaInP intermediate layer 8', and a p-type GaAs cap layer 9' are formed in a stacking manner in this order on the p-type GaInP etching stop layer 6. Thus, a stacked semiconductor structure 16' is produced. Then, an Al₂O₃ layer 10' (oxide layer) is formed on the p-type GaAs cap layer 9' by electron beam (EB) deposition.

Next, as shown in Figure 2B, the stacked semiconductor structure 16' and the Al₂O₃ layer 10' are processed with photolithography and etching, thereby forming a striped ridge structure 16" on the p-type GaInP etching stop layer 6. The striped ridge structure 16" includes the p-type third AlGaInP clad layer 7, the p-type GaInP intermediate layer 8, the p-type GaAs cap layer 9, and an Al₂O₃ layer 10. The striped ridge structure 16" is provided on a central portion of the p-type GaInP etching stop layer 6. The striped ridge structure 16" has a horizontal cross-section which decreases toward the top

surface thereof.

As shown in Figure 2C, the stacked semiconductor structure 17 and the striped ridge structure 16" are rinsed with a sulfuric acid-based rinsing solution, and then washed with pure water. The pure water used in this example is controlled such that the resistivity (representing the purity of the water) is higher than 1 MΩm. Then, the n-type AlInP current confinement layer 11 is formed on the p-type GaInP etching stop layer 6 so as to cover the striped ridge structure 16" by MBE. This step forms an unnecessary layer 12 of n-type AlInP on the Al₂O₃ layer 10.

As shown in Figure 2D, the Al₂O₃ layer 10 and the unnecessary layer 12 are removed. Thus, the n-type AlInP current confinement layer 11 is left on the p-type GaInP etching stop layer 6 and the side surfaces of the striped ridge structure 16 including the p-type third AlGaInP clad layer 7, the p-type GaInP intermediate layer 8, and the p-type GaAs cap layer 9. The p-type GaAs contact layer 13 is formed on the p-type GaAs cap layer 9 and the n-type AlInP current confinement layer 11. Then, the p-type electrode 14 is formed on the p-type GaAs contact layer 13, and the n-type electrode 15 is formed on the bottom

surface of the n-type GaAs substrate 1.

As described above, according to the method of the present invention for producing the semiconductor laser device 100, the pure water used for washing the stacked semiconductor structure 17 and the striped ridge structure 16" has a resistivity of higher than 1 MΩm. The oscillation threshold current I_{th} of the semiconductor laser device 100 is about 30 mA, whereas the oscillation threshold current I_{th} of the semiconductor laser device produced using pure water having a resistivity of 1 MΩm or less is about 40 mA. The oscillation threshold current I_{th} is reduced by about 25% by the present invention. The operating current I_{op} of the semiconductor laser device 100 at an optical output of 7 mW at a higher temperature (80°C) is about 50 mA, whereas the operating current I_{op} of the semiconductor laser device produced using pure water having a resistivity of 1 MΩm or less under the same conditions is about 70 mA. The operating current I_{op} is reduced by about 30% by the present invention. As a result, the operation time in which the average malfunction rate of the semiconductor laser device 100 is kept to be 1% or less is at least 10000 hours, whereas such an operation time of the semiconductor laser device produced using pure

water having a resistivity of 1 MΩm or less is at least 5000 hours. The reliability is improved to about twice as high by the present invention.

5 The interface between the n-type AlInP current confinement layer 11 and the p-type GaInP etching stop layer 6 and the interface between the n-type AlInP current confinement layer 11 and the striped ridge structure 16 (the re-growth interface area of the n-type AlInP current
10 confinement layer 11) was analyzed using a SIMS. The following was found.

 The total content of carbon-based impurities and oxygen-based impurities is as low as less than $1 \times 10^{17}/\text{cm}^3$.
15 That is to say, the effect of using pure water having a resistivity of higher than 1 MΩm is remarkably obtained. In a semiconductor laser device produced using pure water having a resistivity of less than or equal to 1 MΩm, the content of each of carbon-based impurities and
20 oxygen-based impurities at the re-growth interface area is as high as $1 \times 10^{17}/\text{cm}^3$ or higher.

 If the interface of a ridge structure (waveguide) or the like of a semiconductor laser device, where light

is converged, contains a high content of carbon-based impurities and a high content of oxygen-based impurities, light is absorbed by these impurities. This results in deterioration of characteristics such as the oscillation
5 threshold current I_{th} and the like, and generation of, for example, DLD (dark line defect) due to the energy of the light absorbed by these impurities. The dark line causes local deterioration of the ridge structure. In consequence, the reliability of the semiconductor laser
10 device is lowered.

It was also confirmed that LEDs, and light emitting devices using other materials, for example, GaAlInN-based, AlGaAs-based, InP-based and ZnSSe-based materials, which
15 were produced by substantially the same method as the method described in the example of the present invention with reference to Figures 2A through 2D, provided substantially the same effect.

20 As described above, according to a semiconductor light emitting device of the present invention, the interface between the semiconductor current confinement layer and the semiconductor etching stop layer and the interface between the semiconductor current confinement

layer and the ridge structure each have an impurity content of less than $1 \times 10^{17}/\text{cm}^3$. Therefore, light absorption by impurities is suppressed, the oscillation threshold current I_{th} is stable without being abnormally increased, 5 the malfunction rate when continuously used for a long period of time is lowered, and the reliability is improved.

Various other modifications will be apparent to and can be readily made by those skilled in the art without 10 departing from the scope and spirit of this invention. Accordingly, it is not intended that the scope of the claims appended hereto be limited to the description as set forth herein, but rather that the claims be broadly construed.